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EVALUATION OF ROUGHENED DUCT WITH SIMILAR WIDENESS GAP OF ARC WITH STAGGERED LINK AND COMPARISON WITH SIMILAR RIB ROUGHNESS GEOMETRIES

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ABSTRACT

This paper introduces new roughness used in roughened duct and evaluates the effective performance for wideness gap of arc with staggered link geometry. The present new roughness geometry has parameters like obstacle pitch of rib P'/P as 0.4, relative wideness of arc gap g/e as 3, ratio of arc stumble link to rib diameter (r/e) as 3 and arc angle (α) as 30°, gaps on either side of full arc as a number (Ng) of 3, rib pitch with respect to rib height (P/e) as 10 and dimensionless number of Reynolds (Re) as range of 3500 -14000. Turbulence geometries such as similar wideness gap of arc with staggered link, continuous arc rib, arc with gap rib and arc with a gap with obstacle element for rib pitch with respect to rib height (P/e) as 10 were tested. Highest factor of friction coefficient and Nusselt number is obtained to be 3.94 and 1.99 respectively for similar wideness of arc gap with stamble link. Evaluation of THP of similar wideness arc gap with stamble link roughness is higher than existing arc shaped rib element for all values of dimensionless Reynolds number with limit as 3000 to 14000.

KEYWORDS: Similar Wideness Gap of Arc, Staggered Link, Roughened Duct & Thermo-Hydraulic Parameter

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Original Article

1. INTRODUCTION

Smooth plate tested in solar air heater has poor performance because of laminar sub-layer during flow. The performance of roughened duct is improved by various methods. Rib roughness method is one of the chiefest and economical methods to create turbulence for increased heat transfer rate. Researchers always strive for roughness geometry that provides significant enhancement. Aim of present paper is to propose new arc rib geometry and its effective performance study with roughened duct experimentally and in comparison with shaped of arc roughness reported in literature. Many rib roughness geometries such as transverse, inclined, inclined with gap, V- shape, W-shape and arc shapes in roughened duct have been studied. Prasad and Mullick [1] used transverse shaped rib glued with flat surface of absorber plate of roughened duct. They concluded that increase in roughness efficiency of absorber plate in comparison with smooth plate. Transverse shaped roughness was modified by Sahu and Bhagoria [2] by discretizing the transverse rib. Gap in rib with inclined position suggested by Aharwal et al. [3]. Secondary flow generates through gaps. Momin et al. [4] firstly introduced rib roughness of V-shaped in solar air heater. Karwa [5] experimentally studied V-discrete, V-continuous, inclined and rib in transverse position of flow. Patil AK, Saini JS and Kumar K [6] suggested V- shaped rib with gap on half angle and obstacle link in ahead of each wideness gap of arc piece. Deo NS, Chander S and Saini JS [7] investigated on multiple-gap in V shaped ribs and obstacle element. Maithani et al. [8] suggested on symmetrical gap in V-rib. W-shaped rib suggested by Lanjewar

A, Bhagoria JL and Sarviya RM [9]. Kumar A, Saini RP and Saini JS [10] suggested multiple V-rib with gap. Arc rib geometry has been experimentally investigated by various researchers.

Saini et al. [11] firstly introduced continuous arc-rib element. Single symmetrical wideness gap provided on each side of full arc studied by Hans et al. [12]. A symmetrical wideness gap provided on each side of full arc and staggered link studied by Gill et al. [13]. They concluded more Nusselt number than arc rib without staggered piece. 'S' shaped rib geometry studied by Kumar K, Prajapati DR and Samir S [14]. Saini RP and Verma J [15] was investigated dimple shaped artificial roughness geometry on absorber plate for heat transfer and friction behaviour in roughened duct. Early studies on solar air heater include rib element of replicate chamfered shaped rib roughness on a wall broad suggested by Karwa et al. [16] in roughened duct. Varun et al. [17] investigated combination of inclined and transverse piece and examined the thermal performance. It's effect on behaviour flow friction and transfer of heat in duct. Jaurker AR, Saini JS and Gandhi BK [18] analyzed combination of groove and transverse element and explained its effect on heat transfer performance in rectangular duct. Groove position occur in between two roughness element. Layek et al. [19] investigated chamfered modified ribs with grooves and its effect on heat transfer and friction characteristics of roughened duct.

Rate of heat heat transfer, thermal and hydraulic parameter of rib performance improved by gap, obstacle element and concept of reattachment during quantity of air passing through duct. THPP of present geometry performance namely similar wideness gap of arc with staggered link is compared with previous roughness arc geometry.

2. RIB ELEMENT AND PARAMETER VALUES

Figure 1 indicates that schematic program of similar wideness gap of arc with staggered link. Figure 2 indicates that photograph of similar wideness gap of arc with staggered link. The present geometry of similar wideness gap of arc with staggered link having roughness parameters are p/e as 10, P'/P as 0.4, e/D_h as 0.045, g/e as 3, Ng of 3, r/e of 3, and angle of arc as 30^o. Table 1 indicate the values of variables of new rib roughness considered.

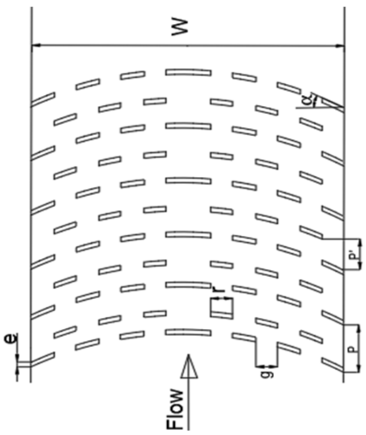

Figure 1: Sketch of New Rib Roughness. **Figure 2: Photograph of New Rib Roughness.**

Table 1: Desired Parameters of Present Rib Geometry.

Variables used in Geometry	Values
Ratio of roughness diameter to hydraulic diameter	0.045
Obstacle pitch of rib	0.4
Ratio of roughness pitch to roughness height	10
Gaps on half portion of arc in number (N_g)	3
Relative arc gap wideness	3

Table 1: Contd.,	
Obstacle element size (r/e)	3
Width of duct	200 mm
Duct height	25 mm
Arc angle (α)	30^o

3. EXPERIMENTAL DETAIL

Experimental setup has entry portion, a test portion, an exit portion and a blower. Rectangular duct having its dimensions of 25 mm depth and 200 mm wide. Test program of the surface plate of roughened area having its dimensions of 1500 mm long and 200 mm wide. The test section zone placed below the electric heater and its absorb heat flux from the bottom surface of heater. Variation of rate of heat transfer per unit surface area with the range of 0–1000 Wm^{-2} adjusted by variac operated by manually. Baffles take in equi-space distance are placed beyond the outlet zone of duct for hot air mixed up in mixing chamber properly. Five thermocouples are fixed after mixing chamber for measuring temperature at the outlet zone of duct. Insulation with outer portion of complete duct section with the help of thermocole. Upper portion of inlet and outlet zone of roughened duct are packed of 8 mm thickness plywood. Thickness of absorber heated surface of 1 millimeter having similar wideness gap of arc with staggered piece on its back side. Quantity of air rate passing through duct is evaluated by Orifice meter connected with U-tube water manometer measuring pressure head. Gate valve measured flow of quantity of air and operated manually which is located on after flexible pipe in linear position. Thermocouple wire diameter as 0.3 mm (24 SWG) made of Cu and Cn. Calibration of Cu-Cn thermocouple wires were utilised for temperature measurement of absorber roughness surface and air flow. The micro manometer is used for measurement of pressure drop in test zone. Friction factor behaviour evaluated on the basis of pressure drop. All data of thermocouples stored in data logger.

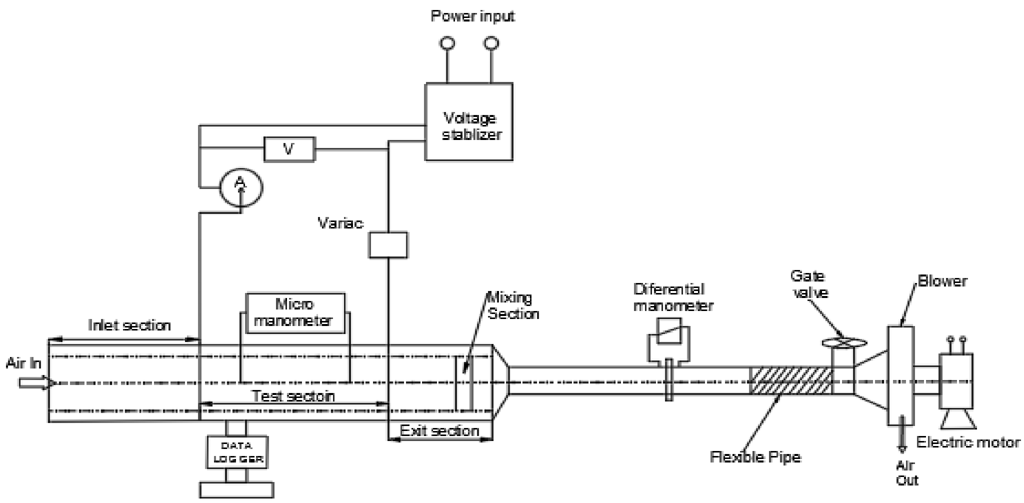

Figure 3: Experimental Test Program.

4. DATA REDUCTION

Surface temperature of absorber plate, Air temperature at inlet and exit temperature of air were measured in steady state criteria. Useful energy gain as a form of heat, coefficient of covection and factor of friction coefficient are calculated.

Heat transfer and factor of friction coefficient parameters evaluated are as follows

$$q = m \times C_p \times (t_o - t_i) \tag{1}$$

$$h = q/[A_p \times (t_p - t_f)] \tag{2}$$

$$Nu_r = (h \times D_h)/\kappa \tag{3}$$

$$f_r = \frac{D_h \times \Delta P}{(2 \times L \times V^2 \times \rho)} \tag{4}$$

5. VALIDITY TEST SET-UP

Validation of test program depends on empirical values and theoretical values. Empirical values of smooth duct are obtained from experiment. From the literature correlations analysis, performance of theoretical values evaluated. Theoretical values of Nu_s evaluated from correlations of Dittus-Boelter (5) and theoretical values factor of friction coefficient evaluated from correlation of modified Blasius (6).

Correlation of Dittus-Boelter used in dimensionless number (Nu) for smoothness [20]

$$Nu_s = 0.024\, Re^{\frac{4}{5}}\, Pr^{\frac{2}{5}} \tag{5}$$

Factor of friction coefficient analysis on the basis of correlation of modified Blasius [21]

$$f_s = 0.085\,(Re)^{-0.25} \tag{6}$$

Figure 4 indicates dimensionless Nusselt number (Nu) verses dimensionless Reynolds number (Re) of smooth surface. Friction factor verses non dimensional number (Re) of smooth surface is given in Figure 5. Empirical values of dimensionless number (Nu) and factor of friction coefficient closely match with theoretical values.

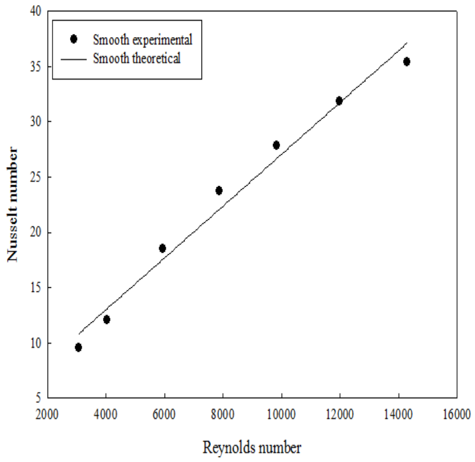

Figure 4: Dimensionless (Nu) verses Dimensionless Reynolds Number (Re) for Smooth Surface.

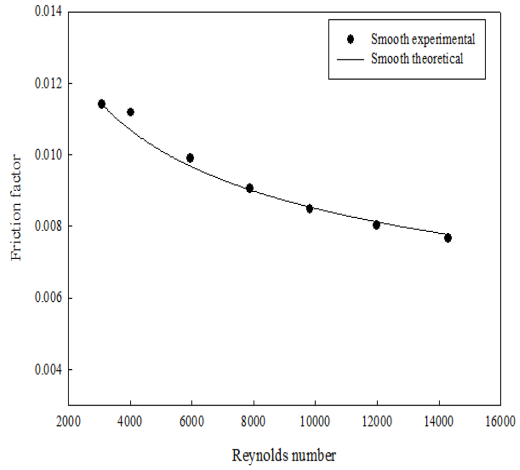

Figure 5: Factor of Friction Coefficient verses Dimensionless Reynolds Number (Re) for Smooth Surface.

6. RESULTS AND DISCUSSIONS

The experimental results of new geometry roughness of rib in comparison with similar reported geometry roughness of ribs. The overall performance for new roughness in comparison with previous reported roughness geometry mentioned in literature.

6.1 Effect of Reynolds Number

Increases the dimensionless Nusselt number (Nu) with increase in dimensionless Reynolds number (Re) as shown in Figure 6. Present new roughness non dimensional number (Nu) is 1.65–1.99 times that of smooth plate over all in limit of dimensionless Reynolds number (Re) studied. The Nusselt number of continuous arc, arc with gap and arc gap with staggered element is 1.38–1.75, 1.45–1.79 and 1.50–1.87 multiple of smoothness surface over entire range of dimensionless Reynolds number (Re) respectively. Decreases of friction factor with increase in dimensionless Reynolds number (Re) as shown in figure 7. Present new roughness friction factor is 3.67–3.94 multiple of smoothness surface over all in limit of dimensionless Reynolds number (Re) studied. The friction factor of continuous arc, arc with gap and arc gap with staggered element is 3.36–3.57, 3.48–3.70 and 3.57–3.79 times that of smooth plate over all in limit of dimensionless Reynolds number (Re) respectively.

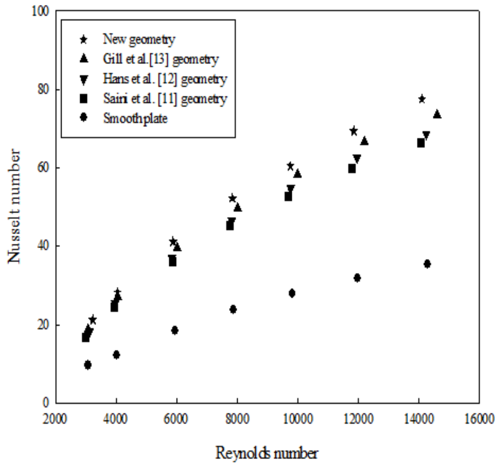

Figure 6: Variation of Nu with Re of new Geometry and Previous arc Geometries.

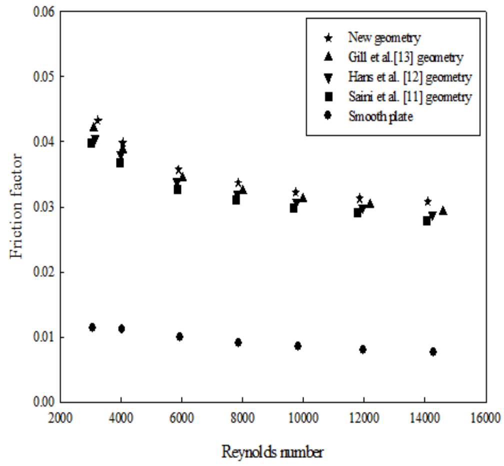

Figure 7: Variation of f_r with Re of New Geometry and Previous arc Geometries.

6.2 Thermo-Hydraulic Performance

Webb and Eckert [22] suggested a THPP for combined evaluation of heat transfer and factor friction coefficient factor as follows

$$\eta = (Nu/Nu_s)/(f/f_s)^{1/3} \tag{7}$$

Benifit of THPP of geometry for present roughness when its values superior than unity in roughened duct. THPP of similar wideness gap of arc with staggered link is compared with the three roughness geometries such as continuous arc rib [11], arc gap in rib element [12] and arc gap in rib element and staggered element [13] by fabrication of previous geometries on absorber surface. Figure 9 indicates the photo-gram of roughness lamina of continuous arc, arc gap in rib element and identical arc gap in rib element and staggered element. Different THPP against with dimensionless Reynolds number (Re) of new geometry along with similar reported arc roughness is given in Figure 8. Figure 8 indicates that THPP

for similar wideness gap of arc with staggered link are more than the value of THPP of similar reported arc geometry.

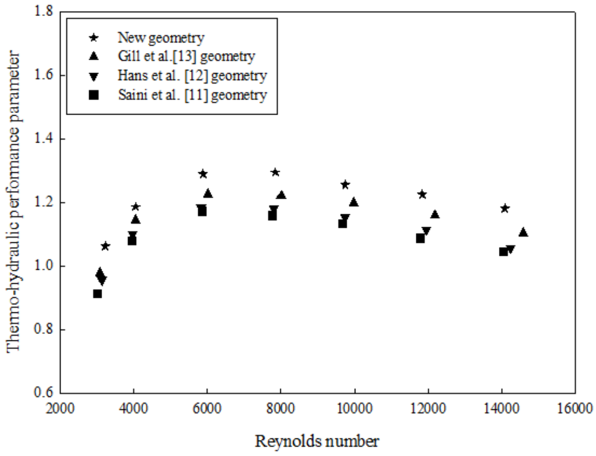

Figure 8: Comparision of THPP with Re for New Geometry and Previous Arc Geometries.

Maximum THPP of Present new roughness is 1.29 for overall in limit of dimensionless Reynolds number (Re). The maximum THPP of continuous arc, arc gap roughness and arc gap with staggered element is 1.17, 1.18 and 1.23 over all limit of dimensionless Reynolds number (Re) respectively.

(a) (b) (c) (d)

Figure 9: Plate Photograph of Similar Wideness Gap of Arc with Staggered Link (a), Arc with Gap Combined with Staggered Link (b), Arc with Gap Roughness (c) and Continuous Arc Roughness (d).

7. CONCLUSIONS

- Present new arc rib geometry increases factor of friction coefficient and Nusselt number maximum by 3.94 and 1.99 times respectively in comparison with smoothness duct.
- THPP comparison of new arc rib element with similar roughness geometries, reveal that the new rib roughness is thermo-hydraulically superior than all previous arc rib geometries.

Nomenclature

C_p	Air Specific heat (J. kg^{-1} K^{-1})
D_h	Equivalent depth of duct (m)
e	Height of rib element (m)
g	Wideness of gap (m)
h	Coefficient of heat transfer for convective (Wm^{-2} K^{-1})
k	Air thermal conductivity (Wm^{-1}K^{-1})
L	Plate length (m)
m	Quantity of air rate passing through duct (kg s^{-1})

N_g	Number of gaps on half arc
P	pitch rib (m)
P'	Obstacle pitch rib (m)
ΔP	Drop in Pressure across test section (N/m^2)
q	Rate of heat transfer (W)
r	Obstacle length in size (m)
t_f	Average temperature of air (K)
t_i	Air temperature at entrance (K)
t_o	Air temperature at exit (K)
t_p	Average temperature of plate (K)
V	Velocity of air (ms^{-1})

Non Dimensional Parameters

e/D_h	Relative roughness height
f_s	Factor of friction coefficient for smoothness
f_r	Factor of friction coefficient for roughness
g/e	Relative gap width
Nu_r	Roughness Nusselt number
Nu_s	Smoothness Nusselt number for smooth plate
P'/P	Relative obstacle pitch
P/e	Relative roughness pitch
Re	Reynolds number
r/e	Relative obstacle rib size

Greek Symbols

α	Angle of arc (Degree)
ρ	Air density (Kgm^{-3})

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